UCRL-ID-136507

Experimentally Determined Coordinates for Three MILS Hydrophones Near Ascension Island

P.E. Harben, J.R. Hollfelder, and A.J. Rodgers

November 19, 1999

Work performed under the auspices of the Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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Abstract

We conducted an airgun survey in the waters of Ascension Island in May 1999 to determine new locations and depths for three Missile Impact Location System (MILS) hydrophones (ASC23, ASC24, and ASC26) currently in use by the Prototype International Data Center (PIDC) and the National Data Center (NDC). The nominal and new locations are summarized in Table 1.

Although not rigorous, errors in the new locations and depths are conservatively estimated to be less than 100 m. The hydrophones are either on or near the ocean bottom in all three cases. The new depths are consistent with the following:

- Direct-phase airgun arrivals.
- Bathymetry determined along the track of the ship used for this airgun survey.
- Reflected phases from the airgun data.
- Depths given in the original hydrophone installation report.

Table 1: Summary of new locations and depths for three MILS hydrophones currently in use by the PIDC and the NDC.

MILS hydrophone	New latitude	New longitude	New depth (km)	Nominal latitude	Nominal longitude	Nominal depth (km)
ASC23	–8.0680	–14.4180	0.84	–8.0697	–14.4175	0.84
ASC24	–8.0570	–14.4470	0.78	–8.0557	–14.4490	0.78
ASC26	–8.9445	–14.6230	1.66	–8.9450	–14.6168	1.66

Introduction

In May 1999, we conducted a series of airgun experiments off the coast of Ascension Island to investigate T-phase coupling and to image the volcanic edifice [1]. We also performed an experimental calibration of the MILS hydrophones that are currently in use at the NDC and the PIDC. These MILS hydrophones (ASC23, ASC24, and ASC26) were installed in 1957 at Ascension Island; they do not have amplitude-response calibration curves, and some uncertainty exists as to their actual locations (nominally a 2-km error). In this paper, we describe the details of the airgun data collected at the three hydrophones and report the new location coordinates for each. The data collected will also be used to determine the calibration curves for each of the three hydrophones; however, these results will be the subject of a future paper.

Ship Track and Shooting Locations

The J.C. Ross, an icebreaker-class oceanographic research ship belonging to the British Antarctic Survey, was hired for four days of airgun shooting in the waters around Ascension Island. This ship was equipped with an 11-airgun array that had a total shooting volume of over 6000 cubic inches. The track of the ship during airgun shooting is shown in Figure 1 with blowups in the immediate vicinity of the nominal locations of the MILS hydrophones. During most of the shooting near the hydrophones, we used a single 1000 cubic inch airgun. This same airgun was fired over a temporary, calibrated hydrophone to provide the source characterization required to determine the calibration curves for the MILS hydrophones.

The ship track was determined by an on-board differential global positioning system (GPS) that archives time and position every second to 1 ms with a 1-m accuracy. For the analysis that follows, the ship track file was corrected to account for the difference in the position of the GPS ship antenna with respect to the towed airgun position (a difference of 92 to 105 m, depending on the airgun towing configuration). The correction used successive GPS positions every minute to determine the true ship heading and assumed that the airgun was towed directly behind the ship (i.e., did not account for current effects). Given the relatively short length of the tow line, the airgun position accuracy is estimated at 10 m. Airgun depth was also corrected. The airgun depth was nominally 5 m when the single gun was fired around ASC26 and 20-m depth at the other hydrophones, when the full airgun array was deployed. The depth position accuracy is estimated to be 5 m.

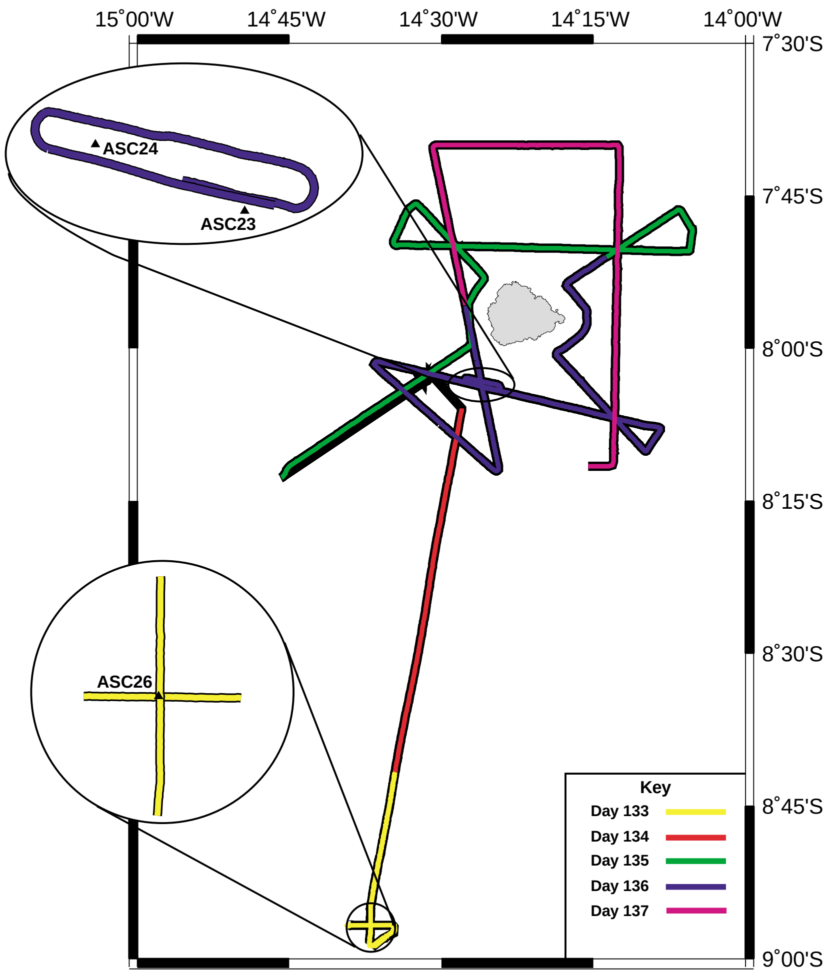

Figure 1. The J.C. Ross shiptrack during airgun shooting in the waters around Ascension Island. The blowups show the track in the immediate vicinity of the three MILS hydrophones and plots their nominal location.

The following sections describe the shot data and location analysis for each hydrophone. ASC26, which is far removed from ASC23 and ASC24, is discussed first. Then ASC23 and ASC24, which are within a few kilometers of each other, are discussed.

ASC26 Location

Figure 2 shows four typical waveforms recorded by ASC26 from nearby airgun shots. These waveforms include a direct arrival at high signal-to-noise and distinct reflected phases. As will be shown, the reflected phases are reflections off the free surface with traveltimes that match the two-way ocean-bottom-to-surface-to-ocean-bottom journey. The MILS hydrophone sampling rate was 120 samples/s, and the estimated accuracy of the first arrival pick is one sample point. The airgun firing time for all shots during the entire experiment was 1.050 s after the minute mark with an estimated zero-time accuracy of 3 ms.

In all, 35 airgun shots were used to determine a new location for ASC26. The direct arrival times were picked for each of the 35 shots and subtracted from the known shot's zero time to obtain a direct-path traveltime from the airgun to the hydrophone for each shot. The corresponding traveltimes were compared with those determined by a ray-tracing code that uses the nominal sound-speed profile in the region and season [2] at 1-m depth increments. The ray-tracing code determines means and root-mean-square (RMS) residuals from all shot locations for a specific trial hydrophone location in a three-dimensional grid. This procedure is applied to every trial location in the grid with increments of 55 m in latitude and longitude and 3 m in depth. A grid search routine then looks for the trial location in the three-dimensional grid with a minimum RMS value. The location of the hydrophone is obtained from the latitude and longitude

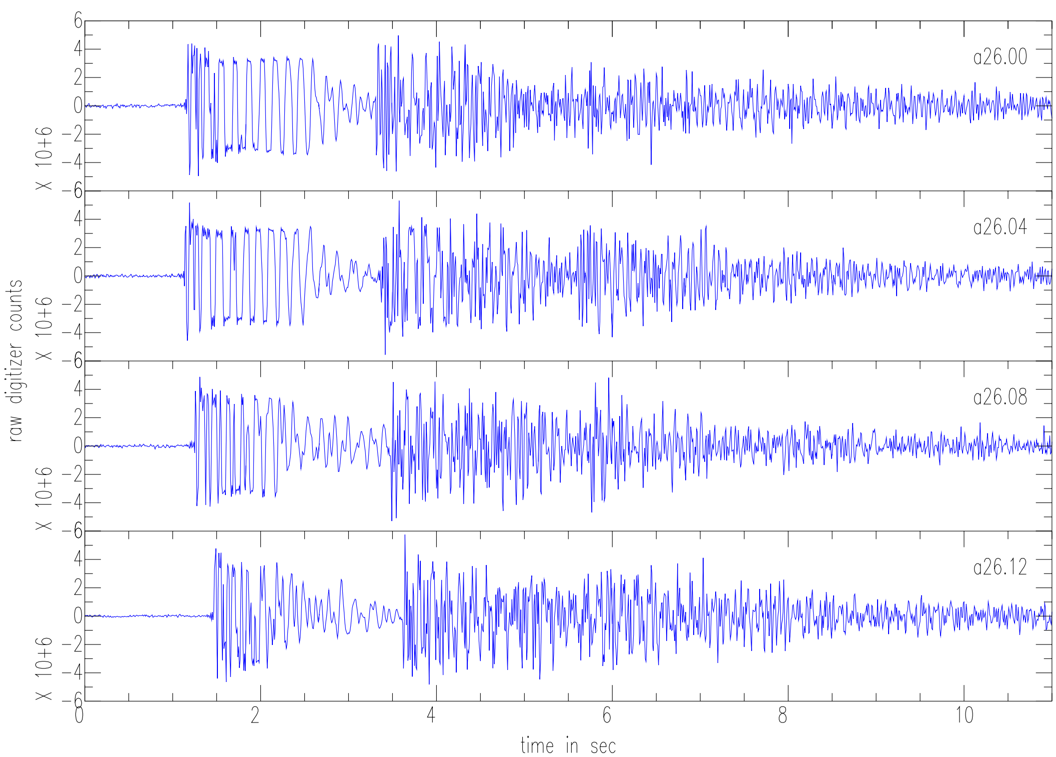

Figure 2. Typical waveform recorded by the ASC26 hydrophone for shots within a few kilometers of the nominal sensor location. A high signal-to-noise direct path arrival is followed by a reflected phase arrival about 2 s later and again 2 s after that.

with the minimum RMS value. The depth of the hydrophone is determined by examining the means at each depth with the same latitude and longitude corresponding to the minimum RMS value. The depth closest to having a zero-mean is taken as the best depth. The results of this procedure applied to the airgun shots for ASC26 are shown in Figure 3. The mean and RMS traveltime residuals for the new location are 0.0001 and 0.033 s, respectively. The near-zero mean indicates there is little bias in the solution. The RMS value is acceptably low. The nominal location of the hydrophone as supplied by the PIDC is also plotted. The airgun data show the location of the hydrophone to be about 0.68 km due west of the nominal location and in close agreement on the latitude.

Figure 4 shows the (1) individual airgun shots, (2) old and new locations for the hydrophone, (3) bathymetry data determined by the J.C. Ross along the ship track, and (4) raw airgun waveforms recorded by ASC26 and aligned with the ship position for that airgun shot. The raw data clearly indicates a hydrophone location consistent with that determined by the location analysis

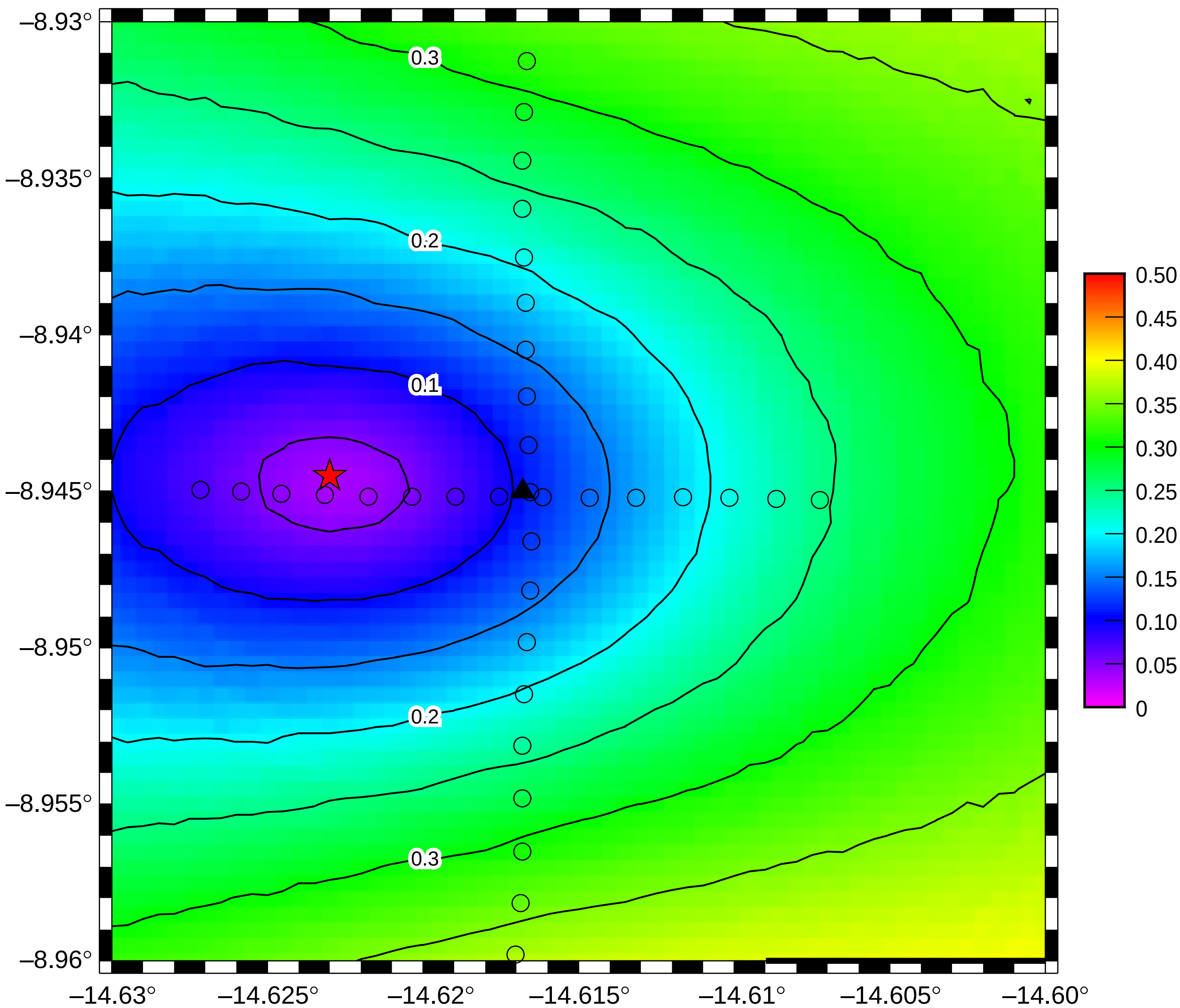

Figure 3. The residual map for ASC26 shows a new location (red star) 0.68 km to the northwest of the old location (black triangle). The color bar gives the traveltime residuals in seconds. Open circles show the location of each airgun shot used in the analysis.

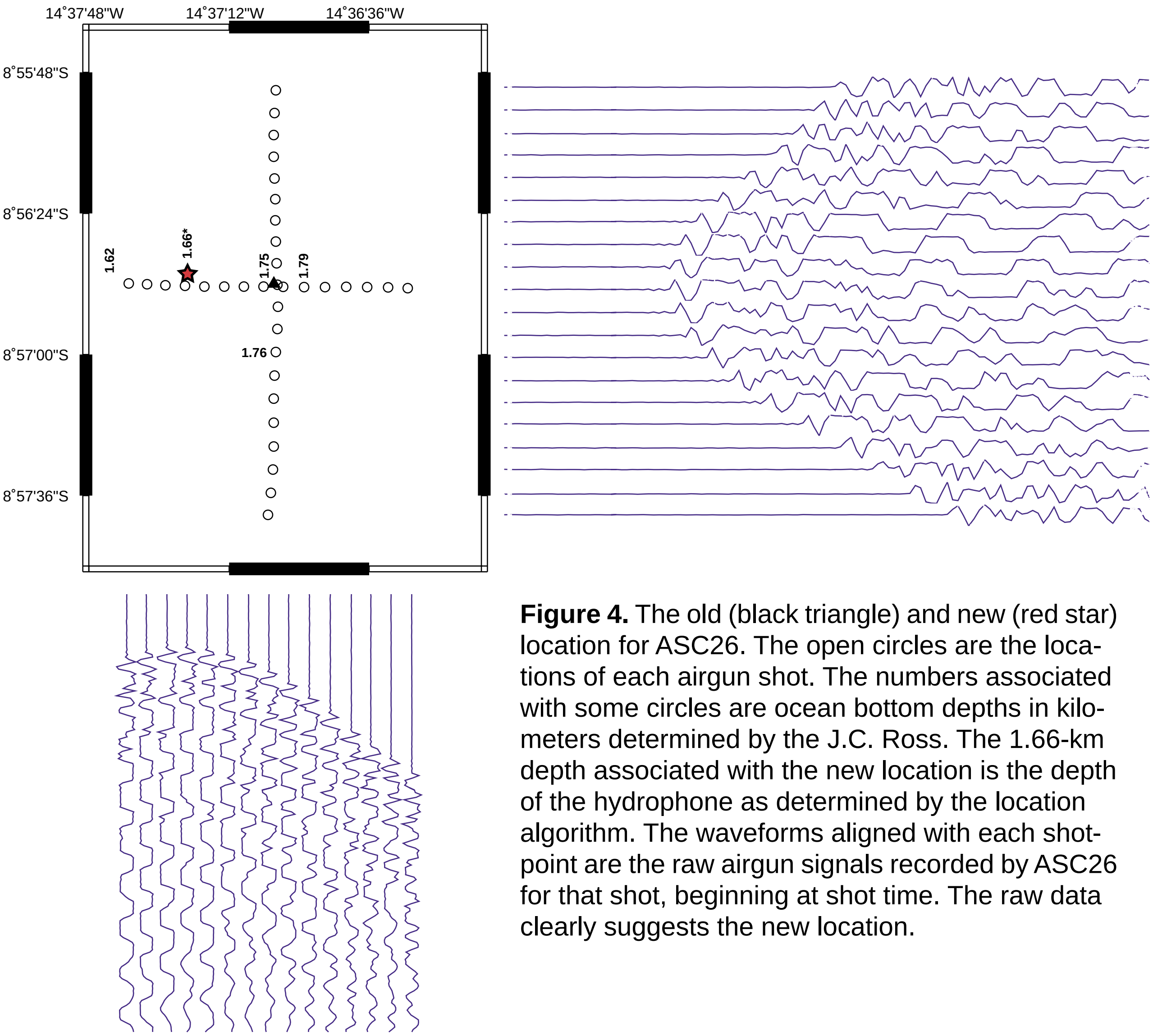

Figure 4. The old (black triangle) and new (red star) location for ASC26. The open circles are the locations of each airgun shot. The numbers associated with some circles are ocean bottom depths in kilometers determined by the J.C. Ross. The 1.66-km depth associated with the new location is the depth of the hydrophone as determined by the location algorithm. The waveforms aligned with each shotpoint are the raw airgun signals recorded by ASC26 for that shot, beginning at shot time. The raw data clearly suggests the new location.

procedure. Furthermore, the bathymetry values determined by the J.C. Ross are consistent with the 1.66-km depth determined for the hydrophone from the airgun data if the hydrophone is located on or near the ocean bottom. The original 1957 installation report [3] gives the depth of ASC26 as 1.66 km with no mention of a floated hydrophone system, which is consistent with the airgun data and J.C. Ross bathymetry.

Finally, the first reflected phase for the airgun shot nearest the new location, as shown in the waveforms in Figure 2, has an arrival time 2.21 s after the direct phase arrival. Integrating the sound-speed profile between 0 and 1.6 km to determine an average acoustic velocity in that interval gives 1.49 km / s. Assuming this phase is the hydrophone-to-surface-to-hydrophone path, the hydrophone depth is 1.65 km, consistent with the 1.66 km result determined by the direct airgun phases. The absence of other phase arrivals, such as a bottom reflection-to-hydrophone phase, is again consistent with a hydrophone location very near or at the ocean bottom.

ASC23 and ASC24 Locations

The racetrack pattern around ASC23 and ASC24 resulted in a large number of airgun shots in the vicinity of both hydrophones. Although all of the data was initially used in the location analyses, we observed an improvement in the mean and RMS fits when direct traveltime paths greater than 1 s were omitted from the analyses. Consequently, the locations for ASC23 and ASC24 were conducted with all airgun shots that had less than a 1-s traveltime (e.g., were less than 1.5 km from the hydrophone). The reasons for the higher RMS values using all of the airgun data could be due to (1) errors introduced by complications in the direct arrival by shadowing from bathymetric features, and (2) errors in the ray-tracing routine and the sound-speed profile, all of which are compounded by lower-angle ray paths.

The new ASC23 location was determined using 46 airgun shots. The results are shown in the residual map of Figure 5. The new location is about 0.20 km to the northwest of the nominal

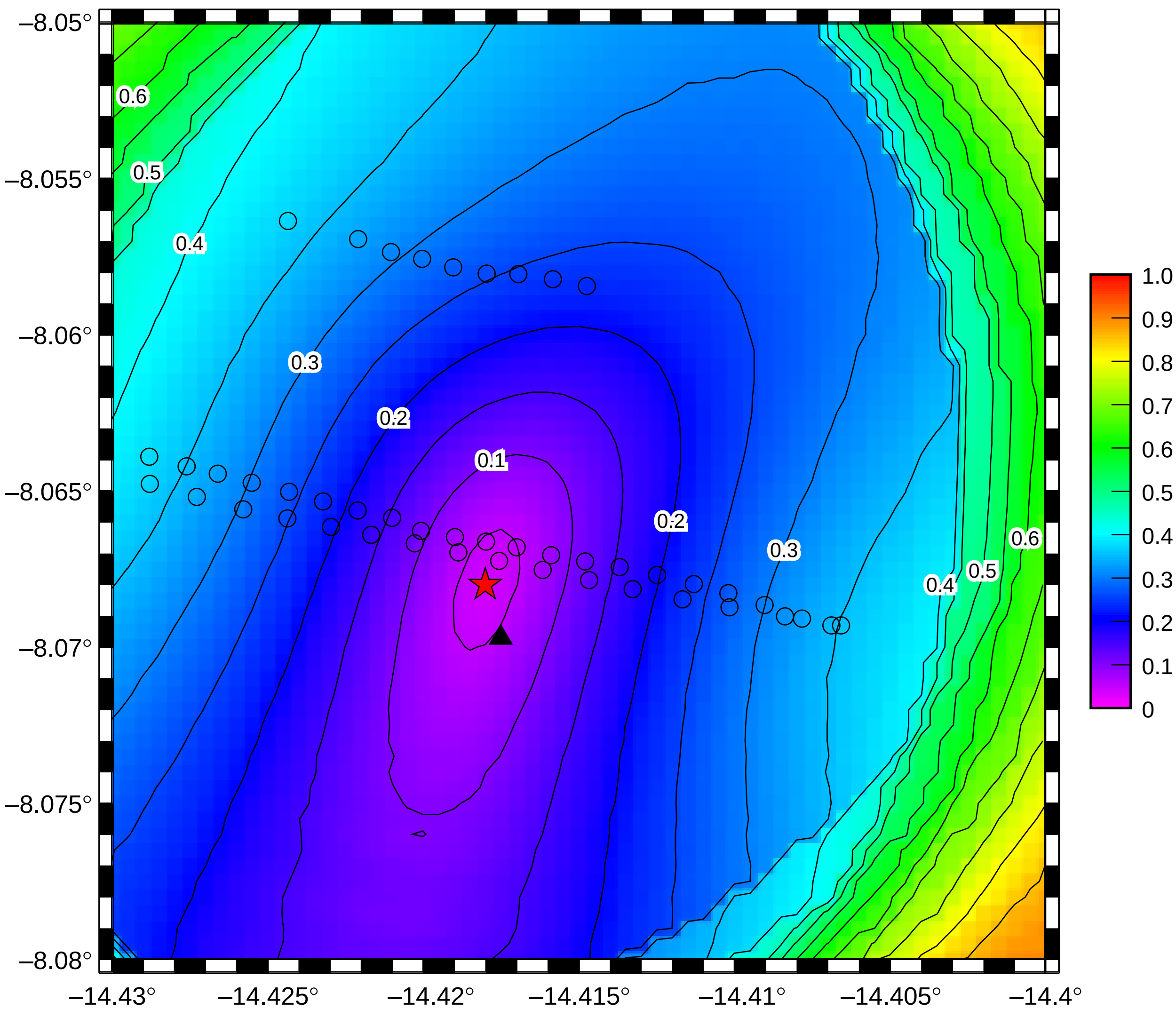

Figure 5. The residual map for ASC23 shows a new location (red star) 200 m to the northwest of the old location (black triangle). The color bar gives the traveltime residuals in seconds. Open circles show the location of each airgun shot used in the analysis.

location, and the depth agrees with the nominal depth of 0.84 km.The mean and RMS of the traveltime residuals were 0.00014 and 0.0331 s, respectively. The near-zero mean indicates there is little bias in the solution, and the RMS value is reasonably low.

The ASC24 location used 35 shots, which resulted in a mean and RMS traveltime fit of 0.00571 and 0.042 s, respectively. The mean and the residual are somewhat larger than for ASC23, but still relatively low. The ASC24 residual map is shown in Figure 6. The new location is about 0.26 km to the southeast of the nominal location, and the depth agrees with the nominal depth of 0.78 km.

The old and new locations for ASC23 and ASC24 are summarized in Figure 7. The old (black triangle) and new (red star) locations are in overall close agreement. The open circles show the airgun shots used for each location analysis. The filled-in circles are airgun shots that were not used because the traveltime to the nearest hydrophone exceeded 1 s. The depths with an asterisk were determined in the analysis. The other depths are associated with the nearest circle and are

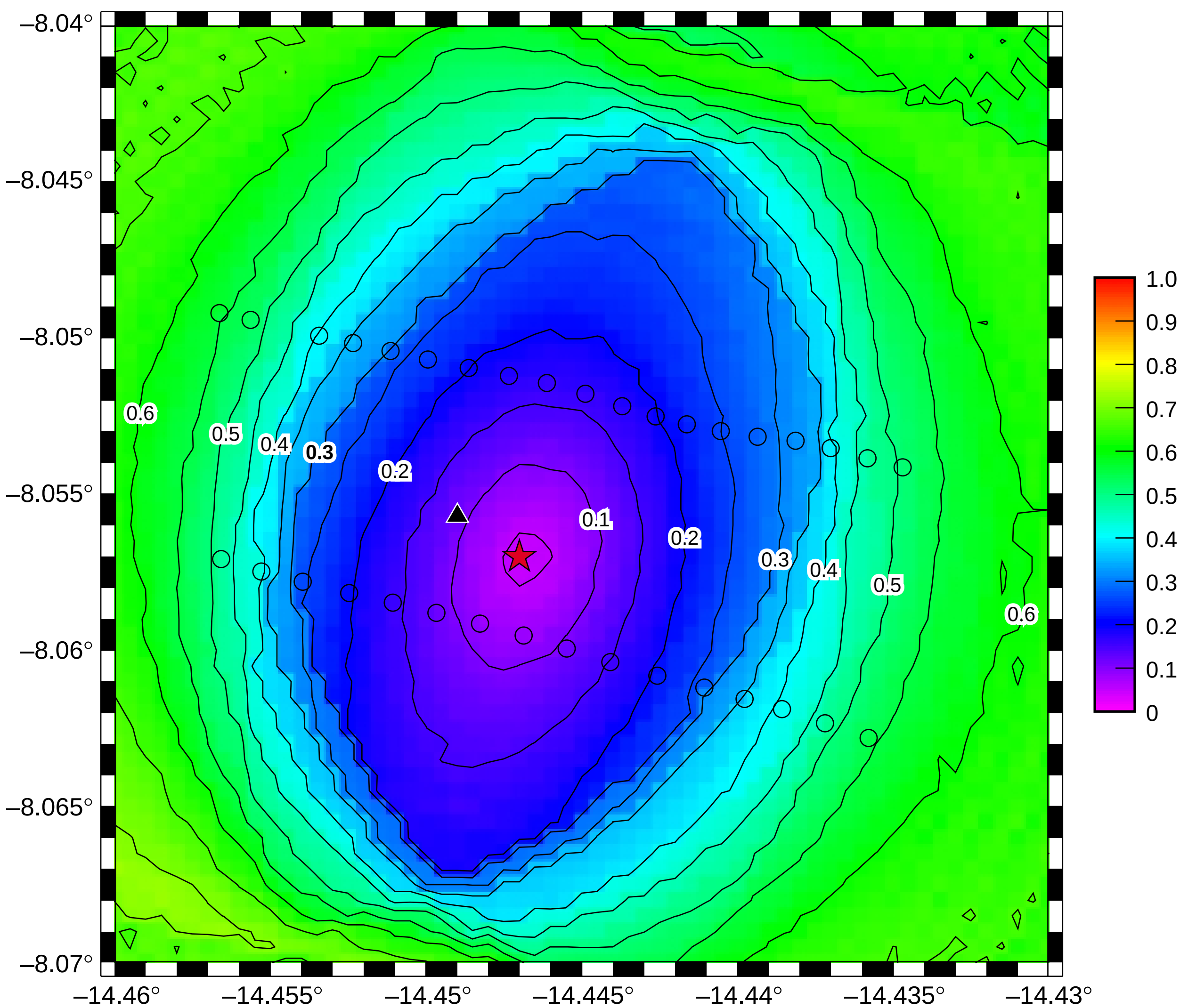

Figure 6. The residual map for ASC24 shows a new location (red star) 260 m to the southeast of the old location (black triangle). The color bar gives the traveltime residuals in seconds. Open circles show the location of each airgun shot used in the analysis.

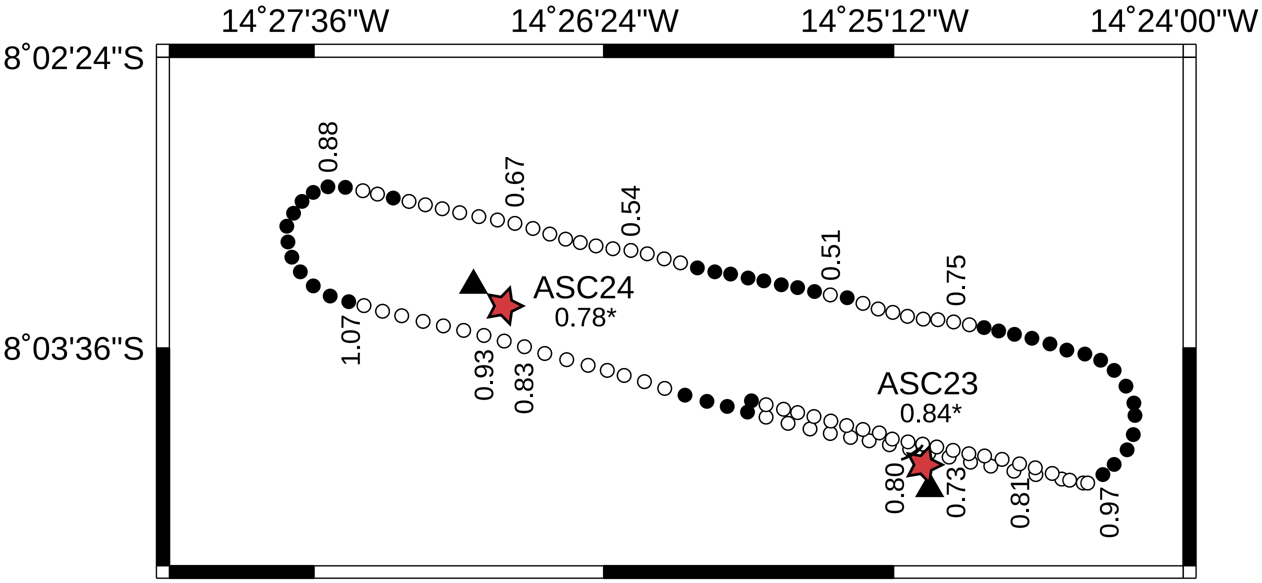

Figure 7. The old (black triangle) and new (red star) location for ASC23 and ASC24. The open circles are the locations of each airgun shot used in the analysis. Filled circles are locations of airgun shots that were not used in the analysis. The numbers associated with some circles are ocean bottom depths in kilometers determined by the J.C. Ross. Depths with an asterisk were determined by the location algorithm.

ocean bottom depths in kilometers as determined by the J.C. Ross. The bathymetry in the region shows considerable variability but is consistent with hydrophones that are near to the ocean floor. Traveltimes of reflected phases from ship locations nearest the hydrophones also point to a hydrophone depth that is very near the ocean bottom.

Conclusions

The three Ascension Island MILS hydrophones currently in use by the NDC and PIDC have been located to an accuracy of at least 100 m in latitude, longitude, and depth. It is clear from the hydrophone depths determined by the airgun shootings, the bathymetry determined by the J.C. Ross, and the original 1957 installation document that the hydrophones are located on or near the ocean bottom. The new locations are all less than a kilometer from the old locations, indicating that the old locations were more accurate than expected. Furthermore, the new depths are within 10 m of the nominal locations.

A towed marine airgun with precision timing and differential GPS logging capability is a good method for determining the position of in-place hydrophones. Other methods to determine hydrophone locations such as air-dropped military calibration charges would have difficulty matching the precision of an airgun because the inherent location and zero-time errors are larger, the pattern of charges is more difficult to control, and the number of charges used has practical and cost-driven limitations. Small implosive sources such as lightbulbs on ships have been used as hydtrophone calibration sources and may be useful in location, though the precision of the position determination and the ease in deploying a large number of sources need to be studied.

It is not necessary to have a ship as large or as capable as the J.C. Ross to accomplish a location survey using airguns since this method only requires a relatively small single airgun with precision timing and location. Such a system could be temporarily mounted on a relatively small ship near the survey location to minimize cost.

Airgun data also has the potential for calibration of in-place hydrophones provided a temporary or permanent calibrated hydrophone can be used to determine the airgun source term. Since the airgun is generally a very repeatable source, once the source term is determined, it can be used to calibrate the amplitude response of the in-place hydrophones. An alternative strategy to calibrate an in-place hydrophone is the temporary placement of a calibrated hydrophone as close as possible, using ambient correlated background noise as the “source.” Data collected during the Ascension Island experiment over a temporary calibrated hydrophone will be used to calibrate the MILS hydrophones. The results will be published in a future report.

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Acknowledgments

Thanks to the Ascension Island experiment team for helping to clarify a number of technical issues that came into question during the course of this analysis. In particular, our gratitude to Tim Minshull and his group from University of Southampton / University of Cambridge, England. Thanks also to Donna Blackman and her group from Scripps Institute of Oceanography, and to Vicki Childers and her group at the Naval Research Laboratory. We are indebted to Keith McLaughlin of the Center for Monitoring Research for special efforts in providing the MILS data during the experiment as well as providing useful background information on the MILS hydrophones that was used in this analysis. Thanks to Joe Schrodt of the Air Force Technical Applications Center for supplying useful information on the MILS hydrophones and perspective on operational history and nominal location errors. Finally, thanks to Don Rock for technical support throughout the experiment.